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The Noise Exposure of Operators of Mobile Machines in U.S. Surface Coal Mines, 1979

By J. H. Daniel, J. A. Burks, R. C. Bartholomae, R. Madden, and E. E. Ungar

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THE NOISE EXPOSURE OF OPERATORS OF MOBILE MACHINES IN U.S. SURFACE COAL MINES, 1979

by

J. H. Daniel,[1] J. A. Burks,[2] R. C. Bartholomae,[3] R. Madden,[4] and E. E. Ungar[5]

ABSTRACT

This report, summarizing the results of two studies sponsored by the Bureau of Mines, presents information on the types of mobile machines used in surface coal mines in the United States, and the amount of noise to which miners are exposed. Data consist of a calculated value of the probability of noise overexposure caused by specific equipment. These data are extrapolated to estimate the number of overexposed operators. Bulldozers were identified as the major contributors to noise overexposure, and the report presents results of a Bureau-funded program on the feasibility of providing retrofit noise control on bulldozers.

INTRODUCTION

Many mobile machines used in U.S. surface coal mines produce noise levels higher than those permitted by the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173) and the Federal Mine Safety and Health Amendments Act of 1977 (Public Law 95-164). Recognizing this problem, the Bureau of Mines sponsored two projects between 1976 and 1979 to identify and control noise levels from these machines. The first project was a census of the types and number of mobile machines in surface coal mines. This project involved noise measurements of mobile machines and an estimate of the total overexposure. The second project was to retrofit noise control of two heavy track bulldozers.

MACHINE CENSUS

Results from a combination of questionnaires and extrapolations show there were approximately 38,500 mobile machines in use at U.S. surface coal

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mines in 1977. Extrapolations were required because, although a questionnaire was mailed to every mine address on the Mine Safety and Health Administration (MSHA) and Bureau of Mines lists, not all mines responded. Two methods of extrapolation were used independently; one was based on production, and the other on survey response rate. Both yielded comparable results.[6]

Table 1, which lists the machines in order of the number in use, shows that two types dominate. Heavy track dozers (>150 hp) are the most numerous, accounting for more than 27 percent of all machines, and they are followed by heavy wheel front-end loaders, which account for more than 16 percent. Together, these two types account for about 43 percent of all machines used in surface coal mines. All types of dozers combined form nearly 30 percent of the total population, and all types of loaders form nearly 20 percent, together accounting for nearly one-half of all machines used in surface coal mines.

TABLE 1. - Ranking of machine types on basis of numbers in use

Rank	Percent	Cumulative percent	Machine
1..........	27.3	27.3	Dozer, track, heavy.
2..........	16.4	43.7	Loader, wheel, heavy.
3..........	14.6	58.3	Hauler.
4..........	7.6	65.9	Truck, highway.
5..........	7.5	73.4	Shovels and draglines, internal combustion power.
6..........	4	77.4	Scraper, tandem.
7..........	3.8	81.2	Motor grader.
8..........	3.4	84.6	Drill, blasthole, without cab.
9..........	3.3	87.9	Drill, blasthole, with cab.
10..........	3	90.9	Scraper.
11..........	2.5	93.4	Loader, wheel, light.
12..........	1.7	95.1	Dozer, track, light.
13..........	1.3	96.4	Shovels and draglines, electric, <30 cu yd.
14..........	1.0	97.4	Shovels and draglines, electric, >30 cu yd.
15..........	.8	98.2	Auger, coal, high-wall.
16..........	.8	99	Loader, track.
17..........	.5	99.5	Dozer, wheel.
18..........	.3	99.8	Drill, coring, truck-mounted.

NOTE.--Heavy = 150 hp or more; light = less than 150 hp.

[6]Ungar, E. E. A Census of Mobile Machines Used in U.S. Surface Coal Mines. BuMines Open File Report 78-077, 1977, 174 pp. (Contract J0166057); available for consultation at the Bureau of Mines libraries in Denver, Colo., Twin Cities, Minn., Bruceton and Pittsburgh, Pa., and Spokane, Wash.: at the Department of Energy facilities in Carbondale, Ill., and Morgantown, W. Va.; and the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and from the National Technical Information Service, Springfield, Va., PB 284 112/AS.

Table 2 lists the predominant manufacturers of each major machine category, the predominant models in use, and the percentage of these models in each category. For example, the table shows that Caterpillar dominates the dozer category: Caterpillar manufactures 71 percent of all dozers used in surface coal mines, 47 percent of which are Caterpillar model D9. Caterpillar also manufactures 46 percent of all front-end loaders used in surface coal mines, 18 percent of which are Caterpillar model 988.

TABLE 2. - Major machine models in use in U.S. surface coal mines (see text footnote 6)

Machine	Manufacturer	Model	Percent of machine type population	Machine	Manufacturer	Model	Percent of machine type population
Dozers...	Caterpillar......	D9	47	Highway trucks.	Ford............	F100	4
		D8	17			F600	4
		All	71			All	28
	International....	TD25	11		Mack............	600	4
		All	12			685	3
	Allis-Chalmers...	All	7			All	18
					General Motors...	All	12
Loaders..	Caterpillar......	988	18		Chevrolet........	All	11
		992	10		International....	All	10
		All	46		White...........	All	8
	Hough...........	All	13				
	Michigan.........	All	13	Scrapers.	Caterpillar......	637	18
	International....	All	6			631	12
						657	7
Haulers..	Euclid..........	All	32			All	55
	Caterpillar......	773	10		Terex...........	T524	16
		All	18			All	25
	Wabco...........	All	12		Euclid..........	All	5
	International....	All	10				
	Mack............	All	8	Blasthole drills.	Gardner-Denver...	RDC16	10
	Dart............	All	5			All	15
					Bucyrus-Erie.....	50R	5
Shovels..	Bucyrus-Erie.....	All	26			All	14
	Marion..........	All	19		Chicago Pneumatic	650	9
	Lorain..........	All	11			All	13
	Northwest........	800	4		Robbins..........	All	13
		All	9		Ingersoll-Rand...	All	11
	Lima............	All	8				
	Manitowoc........	3500	4	Graders..	Caterpillar......	12	28
		All	8			16	22
						14	16
Draglines	Manitowoc........	4600	13			All	72
		4500	8		Galion..........	All	12
		All	25				
	Bucyrus-Erie.....	88B	9				
		All	25				
	Lima............	2400	13				
		All	18				
	Marion..........	All	12				
	Page............	All	9				

NOTE.--All refers to all of the manufacturer's models in use.

An obvious first step in reducing noise exposure is the use of operator cabs. Table 3 gives the percentages of machines that have cabs, the size of the mine in which the machine is operated, and whether the cab has any form of noise control (acoustical) treatment. As the table shows, 70 percent of all machines have cabs, nearly one-half of these machines with cabs have some kind of acoustical treatment, and there are more cabs in large mines than in small mines. In addition, there are more acoustically treated cabs on newer machines than on older equipment; acoustically treated cabs came into significant use between 1969 and 1972.

TABLE 3. - Percentages of machines with cabs

Machine	Percent with cab of any kind			Percent with acoustical cab		
	Large mines	Small mines	All mines	Large mines	Small mines	All mines
Dozer, track, heavy	58	57	57	35	29	32
Loader, wheel, heavy	67	70	62	44	44	44
Hauler	25	86	93	57	34	53
Truck, highway	97	92	96	5	10	7
Shovels and draglines, internal combustion power	85	83	78	33	19	26
Scraper, tandem	62	52	60	30	15	26
Motor grader	60	64	61	32	30	32
Drill, blasthole	50	50	50	22	18	22
Scraper	53	27	47	24	8	21
Loader, wheel, light	61	56	59	41	26	35
Shovels and draglines, electric, <30 cu yd	91	80	89	59	25	54
Shovels and draglines, electric, ≥30 cu yd	89	60	86	62	30	58
Dozer, track, light	63	45	57	36	29	28
Auger, coal, high-wall	18	18	18	3	2	2
Loader, track	65	41	50	27	15	20
Dozer, wheel	83	50	81	56	50	55
Drill, coring, truck-mounted	46	50	47	0	17	3
Total	72	60	70	37	30	34

NOTE.--Large = production 100,000 tons per year or more; small = production less than 100,000 tons per year; heavy = 150 hp or more; light = less than 150 hp.

MACHINE NOISE AND OPERATOR EXPOSURE

A major objective of the research was the calculation of the noise exposure of operators of various machines.[7] For this calculation, independent estimates were made of the average working noise level and the time of operation. The average working noise level was defined as that constant noise level that, if present during the entire work cycle, would result in the same noise exposure, or dose, resulting from fluctuating noise levels that actually occur. Computation of the average working noise level requires the typical work cycle to be divided into a number of events, each of which can be defined in terms of a typical noise level and percentage of the work cycle; for example, for a dozer, the typical work cycle consists of dozing, transporting, and backing. It is, in fact, equivalent to the level read from a noise dosimeter measuring noise over one work cycle. An example of the calculation is presented in appendix A, and details of the procedure are given in footnotes 6 and 7.

Data on machinery noise, work cycles, machine usage durations, and shift lengths were collected during visits to nine mines that included both large and small operations, located in the Appalachian, Midwestern, and Western regions. Data on the noise and work cycles of over 80 individual machines were obtained by direct measurement, and these data were supplemented by information extracted from interviews with mine personnel. Additional data were gathered from study reports made available by some mines, from the literature, and from a sample of records submitted by mine operators to one of the MSHA district offices.

Operator exposures were evaluated on the basis of the most reliable data available. Where possible, noise data measured in this program were used. For machine types for which information was inadequate, estimates were based on data in the literature of the MSHA records. Daily exposure durations were taken directly from the MSHA data.

Table 4 shows the mean values and standard deviations of the average working noise levels of the operators of various machines, daily operator exposure durations, and the probabilities of operator overexposure. The data base from which these values are taken is presented in appendix B. A distinction is made to the extent allowed by available data between machines with no cabs, conventional cabs, and acoustical cabs.

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[7] Ungar, E. E., D. W. Andersen, and M. N. Rubin. The Noise of Mobile Machines Used in Surface Coal Mines: Operator Exposure, Source Diagnosis, Potential Noise Control Treatments. BuMines Open File Report 79-098, August 1978, 114 pp. (contract J0166057); available for consultation at the Bureau of Mines libraries in Denver, Colo., Twin Cities, Minn., Pittsburgh, Pa., and Spokane, Wash.; at the U.S. Department of Energy facilities in Carbondale, Ill., and Morgantown, W. Va.; at the National Mine Health and Safety Academy, Beckley, W. Va.; at the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and from the National Technical Information Service, Springfield, Va., PB 299 538/AS.

TABLE 4. - Noise exposures of machine operators (see text footnote 7)

Machine	Cab[1]	Average working noise level, dBA[2]		Daily exposure duration, hours[4]		Overexposure probability, percent	
		Mean	Standard deviation[3]	Mean	Standard deviation[3]	Present criterion[5]	5-dBA-More stringent criterion[6]
Dozers, track, ≥150 hp....	N	103	1.5	6.0	2.8	96	99
	C	98.5	3.0	6.0	2.8	88	96
	A	92.6	4.5	6.0	2.8	49	80
Dozers, track, <150 hp....	T	94(L)	3.5(L)	5.7	3.5	57	83
Dozers, wheel............	N	96(E)	5.0(E)	4.2	2.0	55	81
	C	96.5	2.0	4.2	2.0	65	90
	A	92	6.0	4.2	2.0	32	60
Loader, wheel, ≥150 hp....	N	94.5	1.5	6.3	3.0	74	93
	C	93.5	5.0	6.3	3.0	56	82
	A	84.6	4.5	6.3	3.0	5.9	29
Loader, wheel, <150 hp....	T	97(I)	3.0(I,E)	5.9	3.2	79	93
Loader, track............	T	91.5(L)	4.0(L,E)	5.5	3.8	37	69
Hauler...................	T	88.5	4.5	6.1	2.5	23	57
Truck, highway............	T	85(E)	5.0(E)	3.6	2.0	2.6	14
Scraper, tandem...........	N	92(E)	7.0(E)	5.6	2.3	44	69
	C	91.5	7.0	5.6	2.3	41	67
	A	85	.5	5.6	2.3	0	14
Scraper, single...........	N	96(E)	5.0(E)	5.8	2.6	69	89
	C	95.5	3.5	5.8	2.6	71	92
	A	91	5.0(E)	5.8	2.6	37	69
Motor grader..............	N	96(E)	5.0(E)	5.1	3.1	62	84
	C	95.8(I)	4.0(I)	5.1	3.1	64	86
	A	86.5	5.0	5.1	3.1	11	35
Shovels and draglines, electric, ≥30 cu yd......	T	77.5	6.5	5.3	1.5	1.2	6.2
Shovels and draglines, electric, <30 cu yd......	T	86	4.0	5.8	2.3	6.7	35
Shovels and draglines, internal combustion power	T	91	6.5	5.9	3.7	38	64
Drill, blasthole..........	N	90	2.0	5.6	2.5	20	70
	C	85	5.0	5.1	2.7	7.2	27
	A	83	3.0	5.1	2.7	.2	7.8
Drill, coring.............	T	87(E)	5.0(E)	5.4	2.8	14	40
Auger.....................	T	95(E,M)	5.0(E)	4.1	2.0	48	76

[1]A Acoustical cab, C Nonacoustical cab, N No cab, T All conditions.

[2]Based on Bolt, Beranek and Newman and verified mines data, except as otherwise specified: E Estimated, I Includes literature data, L From literature, M Includes MSHA data. Values are rounded off to nearest 0.5 dBA.

[3]About 70 percent of all values may be expected to fall within 1 standard deviation below and above the mean.

[4]Values are rounded off to nearest 0.1 hour.

[5]90 dBA permissible for 8 hours daily; a reduction factor of 2 in permissible daily exposure duration for each 5-dBA increase above 90 dBA.

[6]85 dBA permissible for 8 hours daily; a reduction factor of 2 in permissible daily exposure for each 5-dBA increase above 85 dBA.

The overexposure probabilities indicate the fractions of the total operator population that suffer overexposure according to the given criteria. These probabilities provide no information about how often (what fraction of the time) the exposure of the operator of a given machine exceeds the permissible limit. These overexposure probabilities are given for two criteria. The first criterion is a regulation specified in the Coal Mine Health and Safety Act of 1969, which permits exposure to 90 dBA for 8 hours per day and prescribes a reduction by a factor of 2 in the permissible daily exposure duration for each 5-dBA noise level increment above 90 dBA. The second, more stringent, criterion permits exposure to 85 dBA for only 8 hours per day and again prescribes an exposure duration reduction for a factor of 2 for each 5-dBA increment.

As shown in table 4, operators of heavy track dozers without cabs are exposed to mean working noise levels of 103 dBA for a mean of 6 hours per day. The last two columns of the table show that 96 percent of the operators of dozers without cabs in surface coal mines are overexposed to noise, according to the current Federal regulations. If the 5-dBA-more stringent criterion is adopted, 99 percent of the operators are overexposed. The procedure for calculating the overexposure probability is given in footnote 7.

Table 4 also shows that when cabs--particularly cabs with noise control treatments--are used on any type of machine, they decrease both working noise levels and the probability of overexposure.

For each of the various types of machines used in U.S. surface coal mines, table 5 shows the total number of machines in use (based on projections developed from the census data), the average number of people operating each machine per day (based on the average number of daily shifts the machines are in use, according to the machine census), and the number of operators in all U.S. surface coal mines who may be expected to be overexposed (according to both the current criterion and the more stringent criterion). The last two columns also show the percentages (in parentheses) of the total number of operators, approximately 56,200, who suffer overexposure.

This table gives two important statistics. According to the present criterion, over 25,000 operators, or nearly 45 percent of all mobile machine operators in U.S. surface coal mines, are overexposed to noise. With the more stringent criterion, the number of operators overexposed to noise increases to over 37,000, or more than 66 percent of the entire operator population.

Table 5 also shows that all types of dozers together are responsible for overexposure of over 13,500, or nearly 24 percent of all surface mine operators; that is, dozers contribute more than 50 percent of all noise overexposures. Loaders, in turn, overexpose more than 4,700 operators, or 8.6 percent of all surface mine operators, and they account for slightly less than 19 percent of all noise overexposures.

TABLE 5. - Projected number of machines and overexposed operators in U.S. surface coal mines (see text footnote 7)

Machine	Cab[1]	Number of machines[2]	Average number of operators per day per machine[2]	Number of overexposed operators[3]	
				Present criterion[4]	5-dBA-More stringent criterion[5]
Dozer, track, ≥150 hp......	N	4,551	1.56	6,816 (12.1)	7,028 (12.6)
	C	2,648	1.56	3,635 (6.5)	3,966 (7.1)
	A	3,447	1.56	2,635 (4.7)	4,302 (7.7)
Dozer, track, <150 hp......	T	584	1.34	446 (.8)	649 (1.2)
Dozer, wheel..............	N	24	1.92	25 (-)	37 (.1)
	C	32	1.92	40 (.1)	55 (.1)
	A	71	1.92	44 (.1)	82 (.1)
Loader, wheel, ≥150 hp.....	N	2,149	1.36	2,163 (3.8)	2,718 (4.8)
	C	1,661	1.36	1,265 (2.2)	1,852 (3.3)
	A	2,991	1.36	240 (.4)	1,179 (2.1)
Loader, wheel, <150 hp.....	T	1,033	1.30	1,061 (1.9)	1,249 (2.2)
Loader, track.............	T	411	1.13	172 (.3)	320 (.6)
Hauler....................	T	5,620	1.52	1,965 (3.5)	4,869 (8.7)
Truck, highway............	T	2,939	1.25	95 (.2)	514 (.9)
Scraper, tandem...........	N	462	1.47	299 (.5)	469 (.8)
	C	393	1.47	237 (.4)	387 (.7)
	A	310	1.47	0 (-)	64 (.1)
Scraper, single...........	N	486	1.33	446 (.8)	575 (1.0)
	C	252	1.33	238 (.4)	308 (.5)
	A	197	1.33	97 (.2)	181 (.3)
Motor grader..............	N	549	1.19	405 (.7)	549 (1.0)
	C	411	1.19	313 (.6)	421 (.7)
	A	450	1.19	59 (.1)	187 (.3)
Shovels and draglines, electric, ≥30 cu yd.......	T	234	3.14	9 (-)	46 (.1)
Shovels and draglines, electric, <30 cu yd.......	T	334	2.20	49 (.1)	257 (.5)
Shovels and draglines, internal combustion power.	T	3,273	1.45	1,803 (3.2)	3,037 (5.4)
Drill, blasthole..........	N	1,316	1.20	316 (.6)	1,105 (2.0)
	C	721	1.75	91 (.2)	341 (.6)
	A	558	1.75	2 (-)	76 (.1)
Drill, coring.............	T	109	1.47	22 (-)	64 (.1)
Auger.....................	T	323	1.53	237 (.4)	376 (.7)
Total.................	NAp	38,539	NAp	25,225 (44.9)	37,263 (66.3)
Average...............	NAp	NAp	1.46	NAp	NAp

NAp Not applicable.
[1]A Acoustical cab, C Nonacoustical, N No cab, T Total, all conditions.
[2]Based on text footnote 6.
[3]Figures in parentheses indicate percentage. Projected total number of operators = 56,226; (-) = less than 0.1 percent.
[4]90 dBA permissible for 8 hours daily; a reduction factor of 2 in permissible daily exposure duration for each 5-dBA increase above 90 dBA.
[5]85 dBA permissible for 8 hours daily; a reduction factor of 2 in permissible daily exposure duration for each 5-dBA increase above 85 dBA.

The next most significant categories lag far behind dozers and loaders. They are haulers, which overexpose nearly 2,000 operators (3.5 percent of all operators, 8 percent of all overexposed operators) and diesel-powered shovels and draglines, which overexpose about 1,800 operators (3.2 percent of all operators, 6 percent of all overexposed operators).

Two facts should be noted, because they have a bearing on the overexposures shown in table 5. Most of the overexposure associated with haulers results from haulers being operated with open windows; haulers whose noise is measured with their windows closed rarely present a noise overexposure problem. Similarly, the data base for shovels and draglines powered by internal combustion engines is biased toward older models because newer models tend to be much quieter. As a result, the overexposures indicated for haulers and for shovels and draglines may be overestimated.

NOISE CONTROL

The extent of operator overexposure and the types of mobile machines responsible for that overexposure, the results of the first study, were published in a Bureau of Mines report in 1978 (see footnote 7). Following this study, the Bureau sponsored additional research to retrofit noise control on two representative machines from the category that had been identified as the most numerous and the most noisy--heavy track bulldozers. Descriptions of this project are prefaced by a general discussion of noise control techniques--the "tools" of noise control.

Major Sources and Paths

In general, the noise from any one source reaches the ear via several paths, both directly, by airborne paths, and indirectly, by reflections from various surfaces. In addition, sound in the form of vibrations may travel along or through structures.

In diesel-powered mining equipment, the engine is generally a major source of noise. Engine noise may come from the exhaust, the intake, and the casing (that is, the block and accessories attached to it)--as well as the cooling fan--often a significant noise source. The transmission, drive train, and hydraulic system also tend to be significant noise sources.

Noise radiated from the various sources may reach the operator by propagating through the air, directly or by reflections. In addition, vibrations produced by the engine and other mechanical components, as well as structural vibrations caused by sounds, tend to propagate along machine structures, thus causing these structures to radiate sound, somewhat like a loudspeaker.

The relative importance of the various noise sources and paths differs for different machine types and models. One fact is basic for all machines, however: Just as repair of small holes in a leaking roof is useless if large holes are left open, reducing the noise of lesser sources and paths has practically no effect on a worker's exposure unless the contributions from the major sources and paths are reduced. In addition, it does not usually make

sense to spend that money to quiet dominant sources and paths to the point where their contributions are far below those of the lesser sources and paths. Overquieting is both impractical and costly.

Noise Reduction of Diesel-Powered Equipment

In general, the noise exposure of an operator of a given machine may be reduced by blocking the paths of sound between the important noise sources and the miner. Usually, for both practical and economical reasons, the primary noise sources cannot be modified or replaced with quieter ones (except relatively early in the development of new machines). Generally, then, the first solution to a problem of mine machine noise is blocking the noise paths, both airborne and structureborne.

Cabs generally are the most efficient way to obstruct the radiation of sound from such sources as engines or transmissions. The effectiveness of such an enclosure increases with the mass of its walls, and effectiveness is greater if the cab is lined with some kind of acoustically absorptive material. If a full cab would present problems of cooling or access, partial cabs or barriers may be used. They tend to be considerably less effective in noise reduction than full cabs because they do not provide the operator with noise attenuation from all directions which increases the operator exposure to both direct and reflected noise. In a partial cab, the noise the operator hears is not passing through it, but traveling around it. As a result, increasing the mass of the barrier (an effective way to reduce noise heard in full cabs), usually results in little noise reduction in partial cabs.

Mufflers obstruct the propagation of sound out of pipes or ducts, primarily by reflecting some of the sound back toward the source so that the reflected pressure waves almost cancel out the outgoing waves. It is important to match engine exhaust mufflers to the engine, so that they will be effective acoustically, yet not produce excessive backpressure. Mufflers are commercially available for almost all pieces of equipment used in U.S. surface mines.

One of the most overlooked ways to reduce noise levels is machine maintenance. Table 4 shows a number of machine categories, such as highway trucks, with standard deviations of 4 dBA or more. This is a significantly large variation between the noise of one machine and another in the same category. There could be several reasons, of course, but experience has shown that a major contribution is the state of repair of the individual machine. Are the seals tight? Are all windows in place? Is the air conditioner working so the operator will not need to open the windows (letting in air and also noise)? Are the floormats in place? Proper maintenance of the machine is a must for successful noise control.

RESULTS OF RETROFIT NOISE CONTROL IN BULLDOZERS

In 1978, the basic principles of noise control described previously were used to quiet two heavy track Caterpillar D9G bulldozers. One had a rollover protective structure (ROPS) only and no operator cab, and the other was

equipped with a standard cab. Before the program, the high-idle sound level at the operator position for the dozer with ROPS only was 105.5 dBA. The noise of the dozer with the cab, under similar high-idle conditions with the doors closed, was measured at 100 dBA. Once the noise control treatments were installed, noise levels at high idle were reduced 11.5 and 12 dBA, corresponding to sound levels of 94 and 88 dBA, respectively, for the two dozers.

Figure 1 shows the dozer that was equipped with ROPS only, with all noise control treatments installed. Visible in the photograph are the muffler and the Lexan[8] windshield, which were installed to block airborne noise from the engine and the fan. The treatments are itemized in table 6, together with the noise reduction the treatment provides at high idle. About 6 dBA of reduction was obtained by applying three major treatments, windshield, muffler, and sound absorption under the ROPS canopy. The remaining 5.5 dBA of reduction was obtained by carefully sealing openings and by isolating the dash from engine vibrations. Materials for the entire treatment package cost less than $1,000 in 1978.

TABLE 6. - Summary of noise control treatments installed on dozer equipped with ROPS only (high idle)

Treatment	Sound level, dBA	Noise reduction from baseline, dBA
1. None (baseline)	105.5	0
2. Windshield	101.5	4
3. Absorption under ROPS	102.5	3
4. Exhaust muffler	104	1.5
5. Windshield and absorption	100	5.5
6. Windshield, absorption, and muffler	99.5	6
7. Windshield, absorption, muffler, and dash seals and isolation	96.5	9
8. Windshield, absorption, muffler, dash seals and isolation, floor seals	95.5	10
9. Windshield, absorption, muffler, dash seals and isolation, floor seals and seat seals.	95	10.5
10. Windshield, absorption, muffler, dash seals and isolation, floor seals, seat seals, tank seal, and hydraulic valve cover	94	11.5

[8]Reference to specific trade names or equipment does not imply endorsement by the Bureau of Mines.

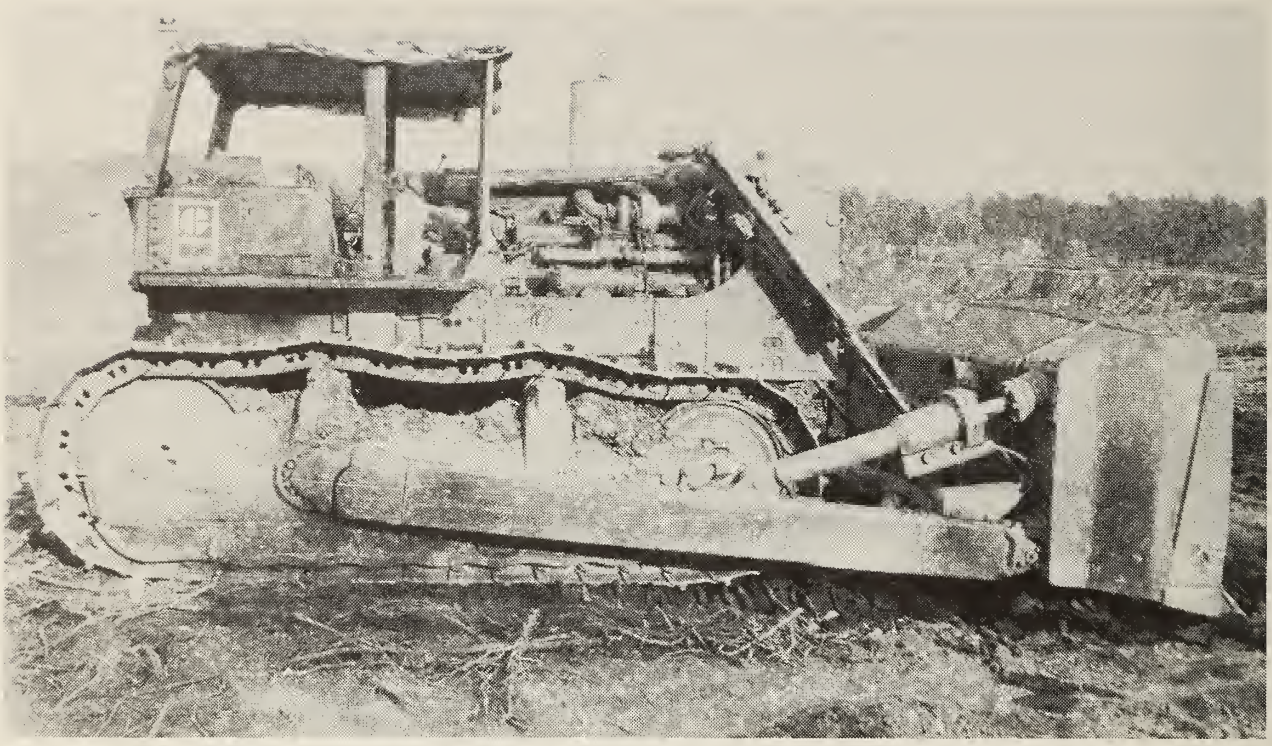


FIGURE 1. - Caterpillar D9G bulldozer with rollover protective structure.

The dozer with the cab is shown in figure 2; all noise control treatments are installed inside the cab. Table 7 lists the treatments, most of which are the same as those previously discussed. Exceptions are seals between the cab walls and the floorboards and the inclusion of additional absorptive material on the fuel tank, on the hydraulic tank cover, and under the dash. The total cost of materials for this package was also less than $1,000 in 1978.

When the noise control treatments were completed, the dozers were placed in service during March and April 1978. Both are currently (1980) operating at surface coal mines in the Eastern United States.

TABLE 7. - Summary of noise control treatments installed on dozer with cab (high idle, doors closed)

Treatment	Sound level, dBA	Noise reduction from baseline, dBA
1. None (baseline)............................	100	0
2. Absorption under ROPS.......................	98	2
3. Cab wall seals and absorption...............	97.5	2.5
4. Absorption, cab wall seals, floormats, and pedal seals...............................	95.5	4.5
5. Absorption, cab wall seals, floormats, pedal seals, seat seals, hydraulic tank cover seals, and blade control seal.............	93.5	6.5
6. Absorption, cab wall seals, floormats and pedal seals, seat seals, hydraulic tank seal, blade control seal, and dashboard isolation................................	88	12

Noise dosimeter readings taken at the operator position on the dozer with ROPS only indicate that the time-weighted average noise is 93.5 dBA, with a standard deviation of 4 dBA during normal operation. This noise level indicates that the dozer will be in compliance with the Federal regulations, without requiring hearing protection for the operator, for operation of 4-1/2 to 5-1/4 hours per day. Dosimeter readings taken on the dozer with cab give the

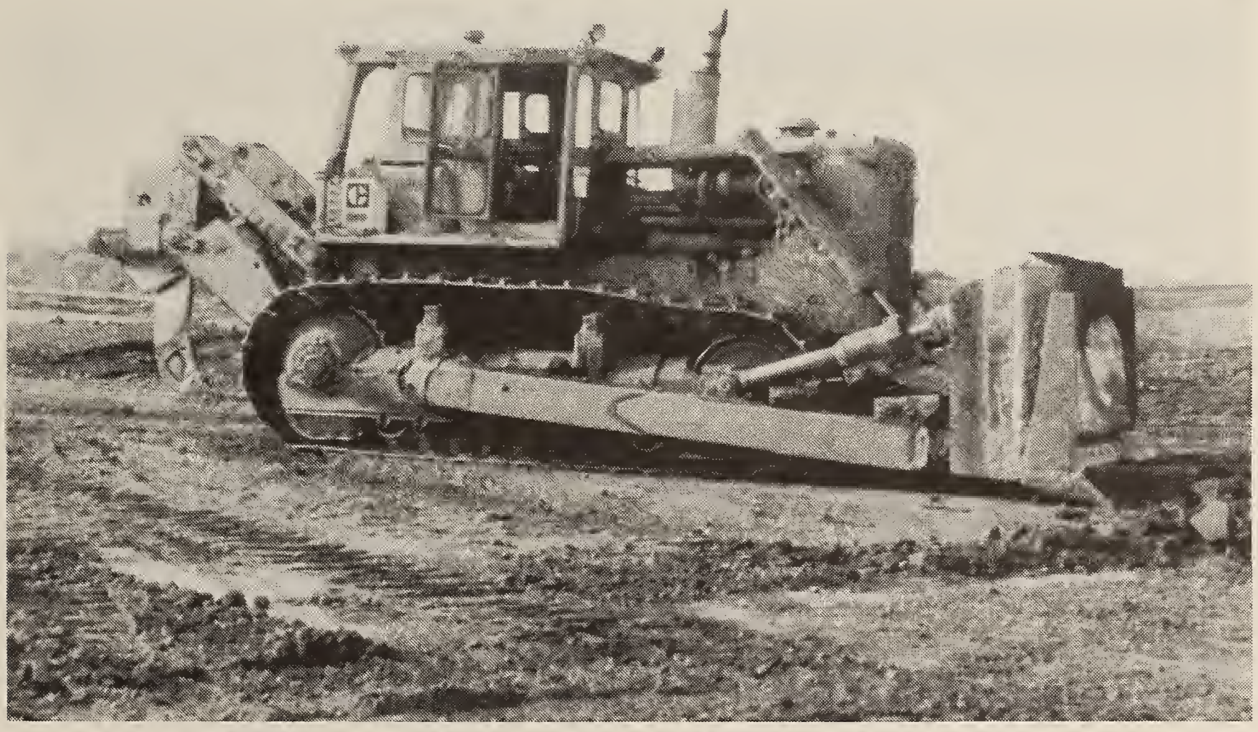


FIGURE 2. - Caterpillar D9G bulldozer with full operator cab.

time-weighted average as approximately 90 dBA. This dozer can, therefore, be in compliance for full-shift operation.

Subsequent inspection visits indicated that these reduced noise levels can be maintained through relatively minor maintenance, primarily of the elastomeric seals.

CONCLUSIONS

The noise exposure of U.S. surface coal miners was evaluated in this Bureau report. A 1977 study indicated that over 25,000 mobile machine operators (nearly 45 percent of the approximately 56,200 operators) were overexposed to noise according to the criterion specified in the Federal Coal Mine Health and Safety Act of 1969 and the subsequent Amendments of 1977. Heavy track dozers were the largest contributors, responsible for 54 percent of the overexposure, and rubber-tired front-end loaders were second in importance, contributing 19 percent of the overexposure. On the basis of these results, the Bureau selected bulldozers for a demonstration of the feasibility of retrofit noise control. The two dozers that were chosen were a Caterpillar D9G with ROPS only and a D9G with a cab. The noise from the dozer equipped with ROPS only was reduced by 11.5 dBA, and the noise from the dozer with the cab was reduced by 12 dBA.

APPENDIX A.--CALCULATION OF AVERAGE WORKING NOISE LEVEL

The average working noise level is a useful concept for characterizing the noise exposure contribution of a given machine that produces nonconstant noise levels. The average working noise level is defined as the constant noise level that results in the same noise dose as the actual nonconstant noise levels, for the period the machine is operating.

For example, consider a machine that subjects its operator to 90 dBA while it idles and to 95 dBA while it is used at full power; assume also that the machine operates at idle for 30 percent of the time it is in use and at full power 70 percent of the time. Note from table A-1 that the permissible exposure duration for 90 dBA is 8 hours and for 95 dBA, 4 hours. Assuming a total of 7 hours of use per day (7 X 0.30 = 2.10 hours at 90 dBA and 7 X 0.70 = 4.90 hours at 95 dBA), a total noise dose of 2.10/8 + 4.90/4 = 1.487 is obtained. The average working noise level in this case is that noise level producing a noise dose of 1.487, if it is continuous for 7 hours.

The permitted exposure duration T in hours is related to the noise dose D and actual exposure duration C in hours as

$$T = C/D. \qquad \text{(A-1)}$$

Thus, there the permitted duration T is 7/1.487 = 4.71 hours. From the values indicated in table A-1, one may observe that the average working noise level is between 92 and 95 dBA. The exact value of 93.8 dBA can be calculated from equation A-2 in table A-1.

The assumed value of the daily use time (taken above as 7 hours) does not affect the value of the average working noise level. The effects of the assumed values of the daily use time cancel, because the same number is used in the dose evaluation calculation and in the determination of the corresponding permitted duration.

TABLE A-1. - Permissible noise exposures

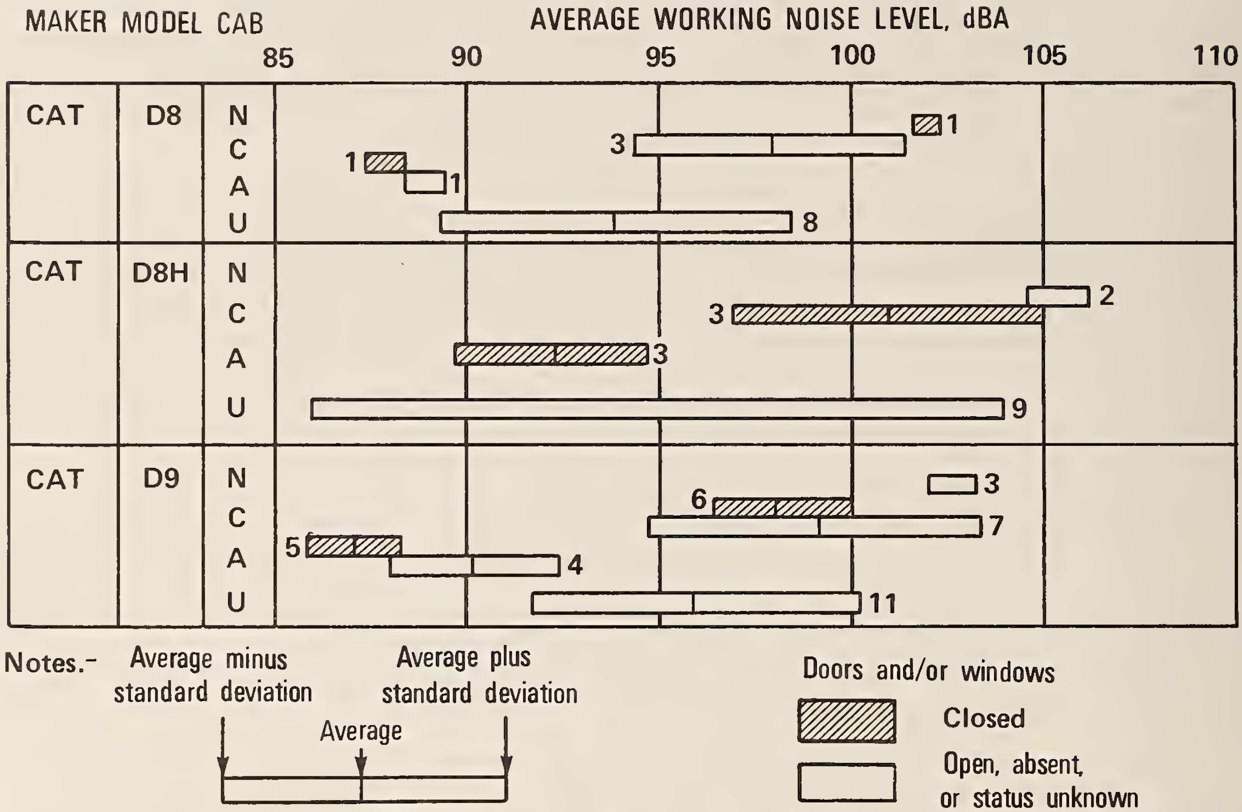
Duration of exposure per day, hours	Noise level, dBA	Duration of exposure per day, hours	Noise level, dBA
8..................	90	1.5................	102
6..................	92	1..................	105
4..................	95	0.5................	110
3..................	97	0.25...............	115
2..................	100		

NOTE.--Noise levels are measured with a sound level meter set to slow response. Exposure to continuous levels above 115 dBA is not permitted by law. Values between those tabulated may be obtained from

$$T = \frac{8}{2^{(L-90)/5}}, \qquad \text{(A-2)}$$

where T denotes the daily exposure duration in hours, and L is the noise level in dBA.

APPENDIX B.--WORKING NOISE LEVEL DATA BASE



Numbers next to bars indicate samples in data base. (When data for only one sample are available, no standard deviation can be calculated; bar is arbitrarily shown 1 dB long, centered on average value.)

Manufacturers' abbreviations

ALC	Allis-Chalmers	GTS	Gates	MSF	Massey-Ferguson
BAT	Bates	GMC	General Motors	MGN	Michigan
BUC	Bucyrus-Erie	HGH	Hough	NWT	Northwest
CAT	Caterpillar	IHC	International	PGE	Page
CHP	Champion	JOY	Joy	PRS	Parsons
CGP	Chicago Pneumatic	KOM	Komatsu	ROB	Robbins
CLK	Clark	KRS	Kress	SLM	Salem
DRT	Dart	LMA	Lima	SRD	Schroeder
DVY	Davey	LOR	Lorain	TRX	Terex
DLT	Drilltech	LTN	LeTourneau	TJN	Trojan
EUC	Euclid	MCK	Mack	UNT	Unit Rig
FIA	Fiat-Allis	MTC	Manitowoc	WAB	Wabco
GRD	Gardner-Denver	MRN	Marion		

KEY

A = Acoustical cab
C = Nonacoustical cab
N = None
U = Unknown MSHA data sample

FIGURE B-1. - Working noise level of dozers.

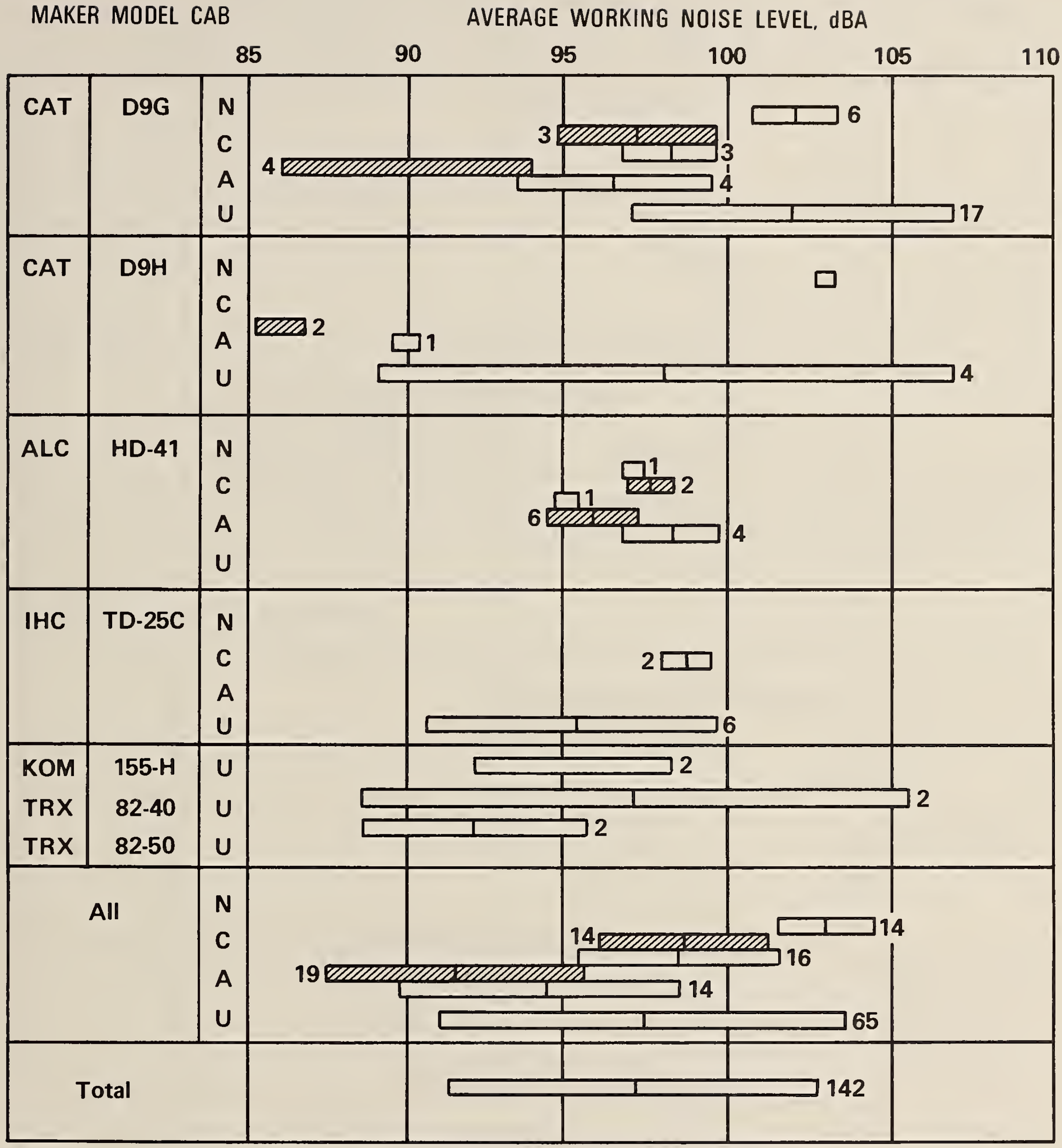
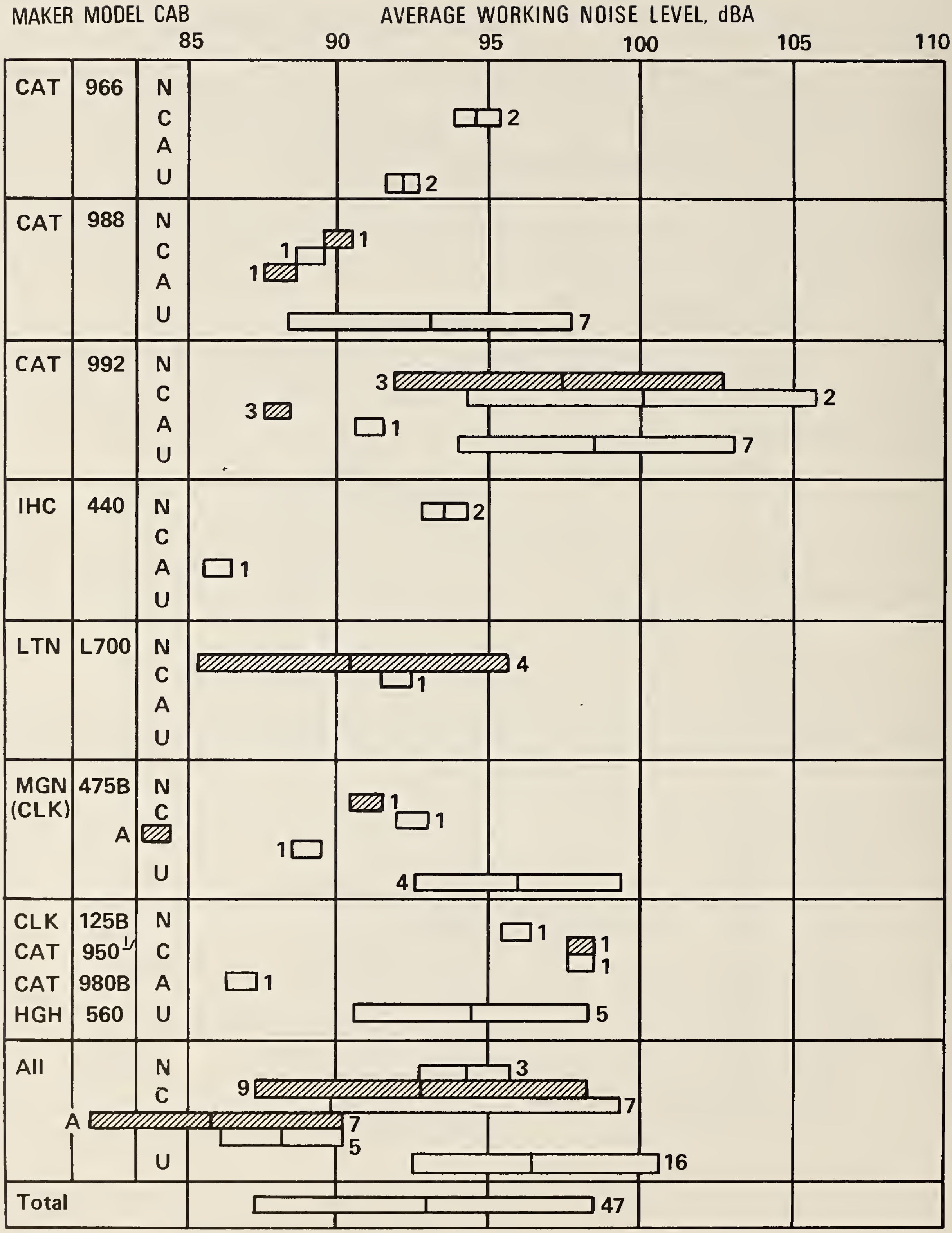


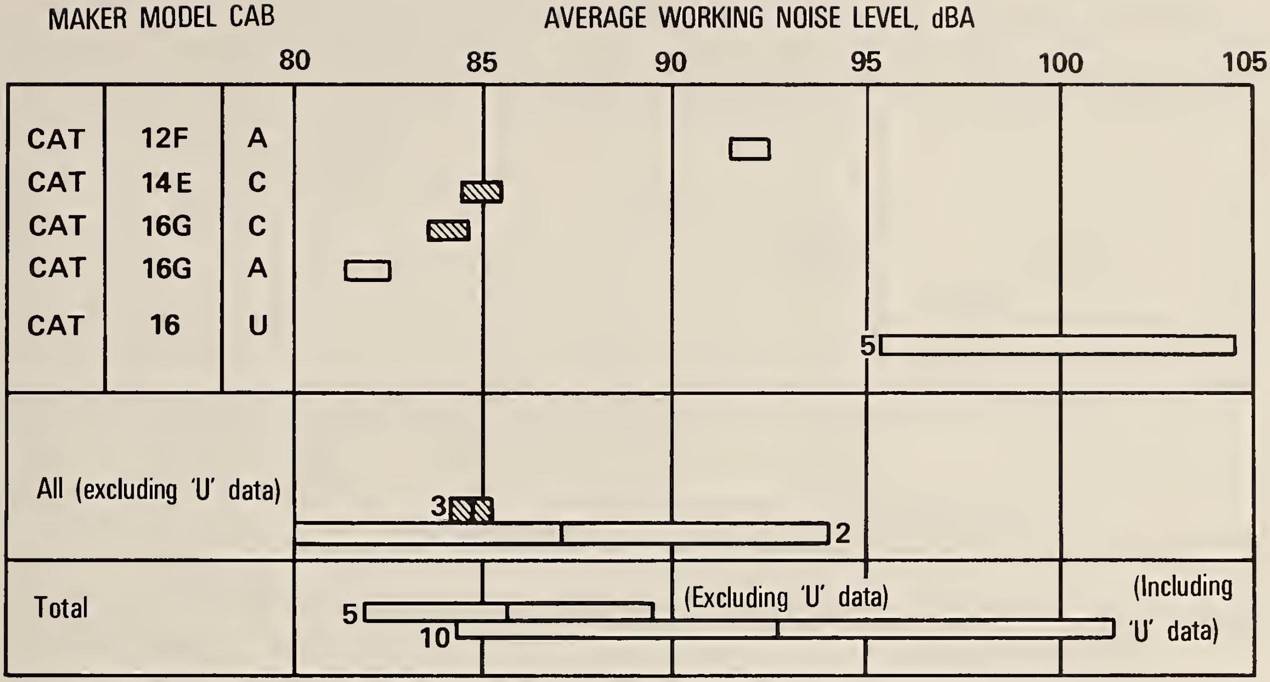
FIGURE B-1. - Working noise level of dozers.—Continued



See figure B-1 for definitions of symbols

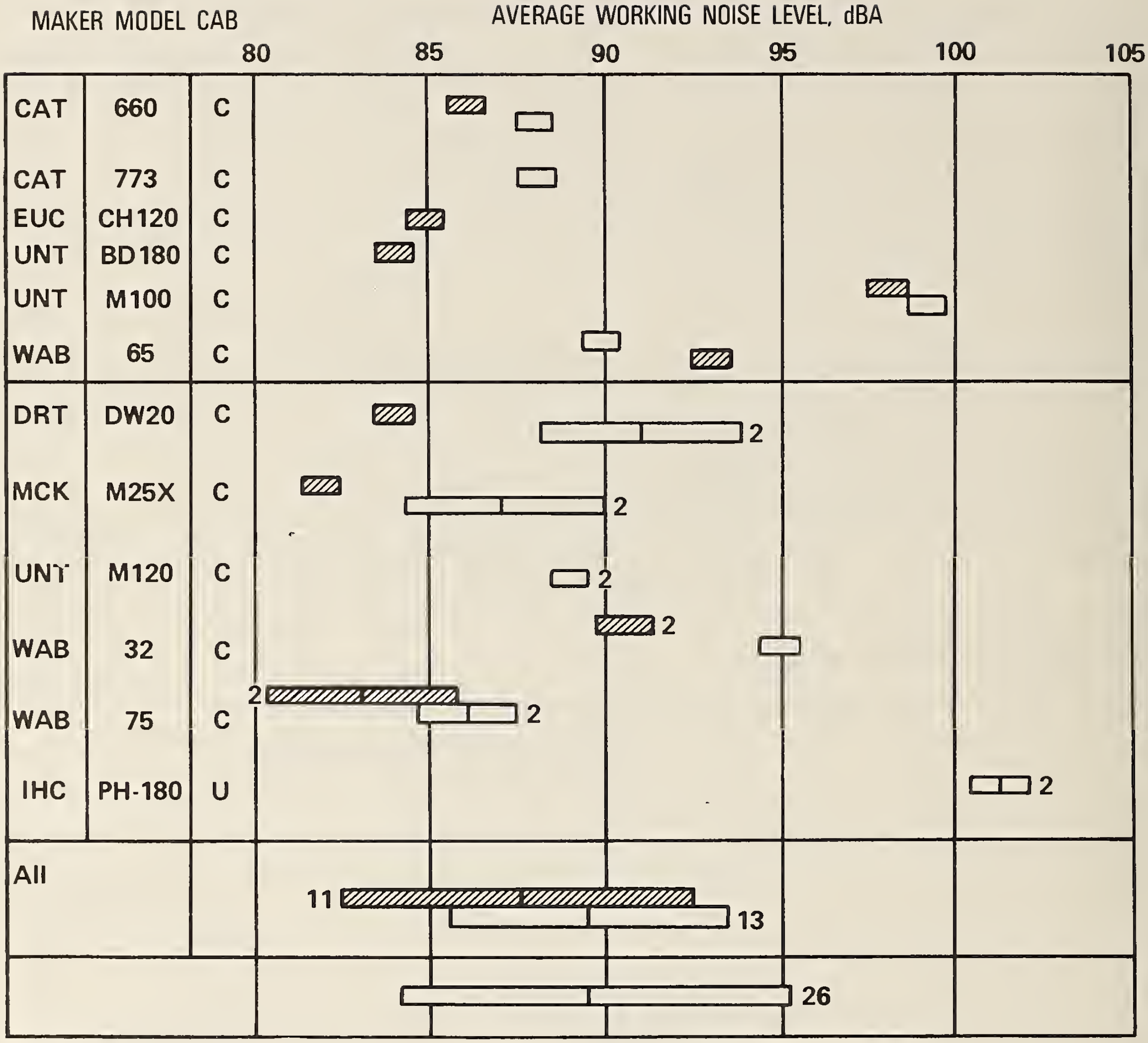
[1] 130-hp machine, all others have over 150 hp

FIGURE B-2. - Working noise level of loaders.



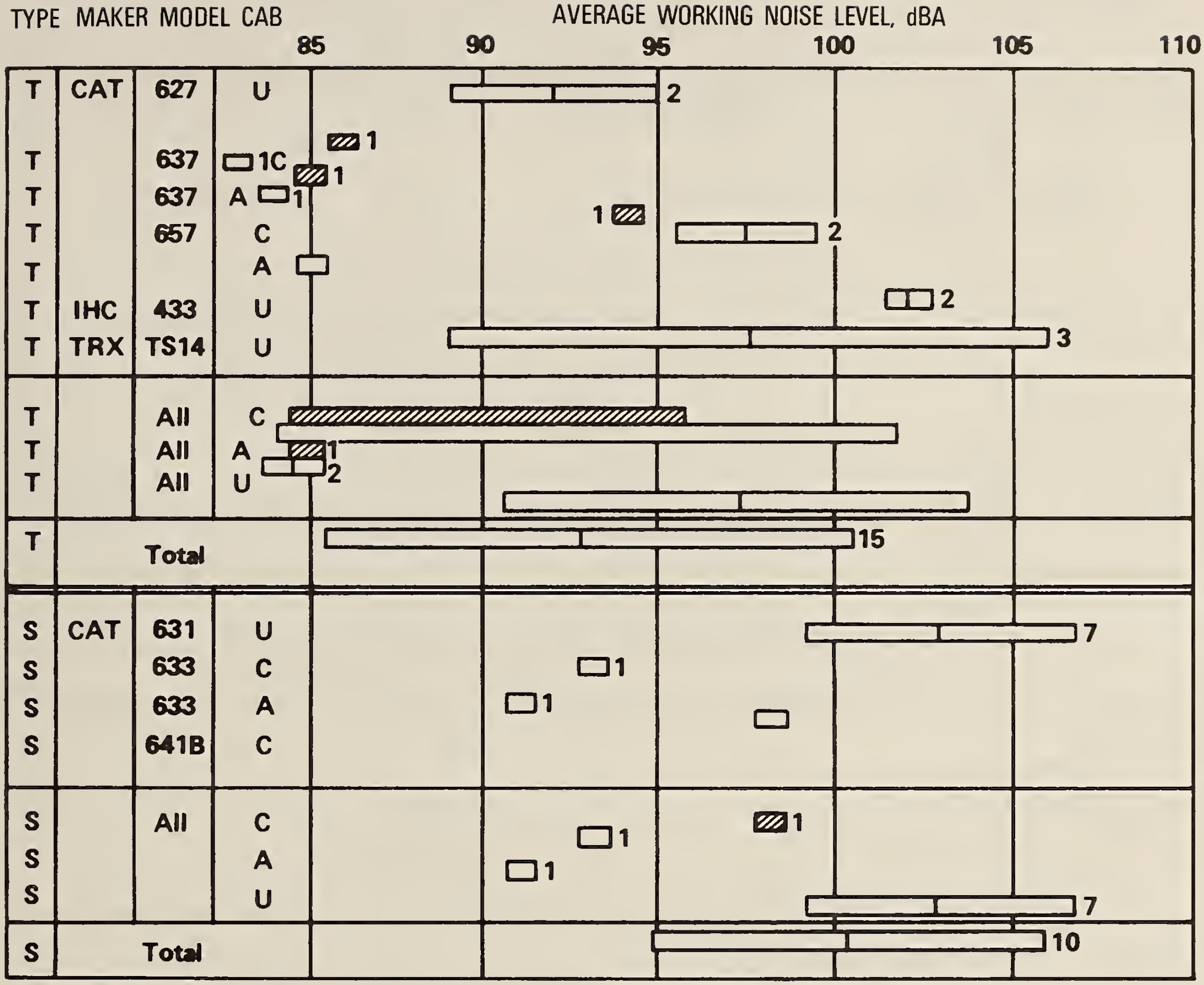
See figure B-1 for definitions of symbols

FIGURE B-3. - Working noise level of motor graders.



See figure B-1 for definitions of symbols

FIGURE B-4. - Working noise level of haulers.

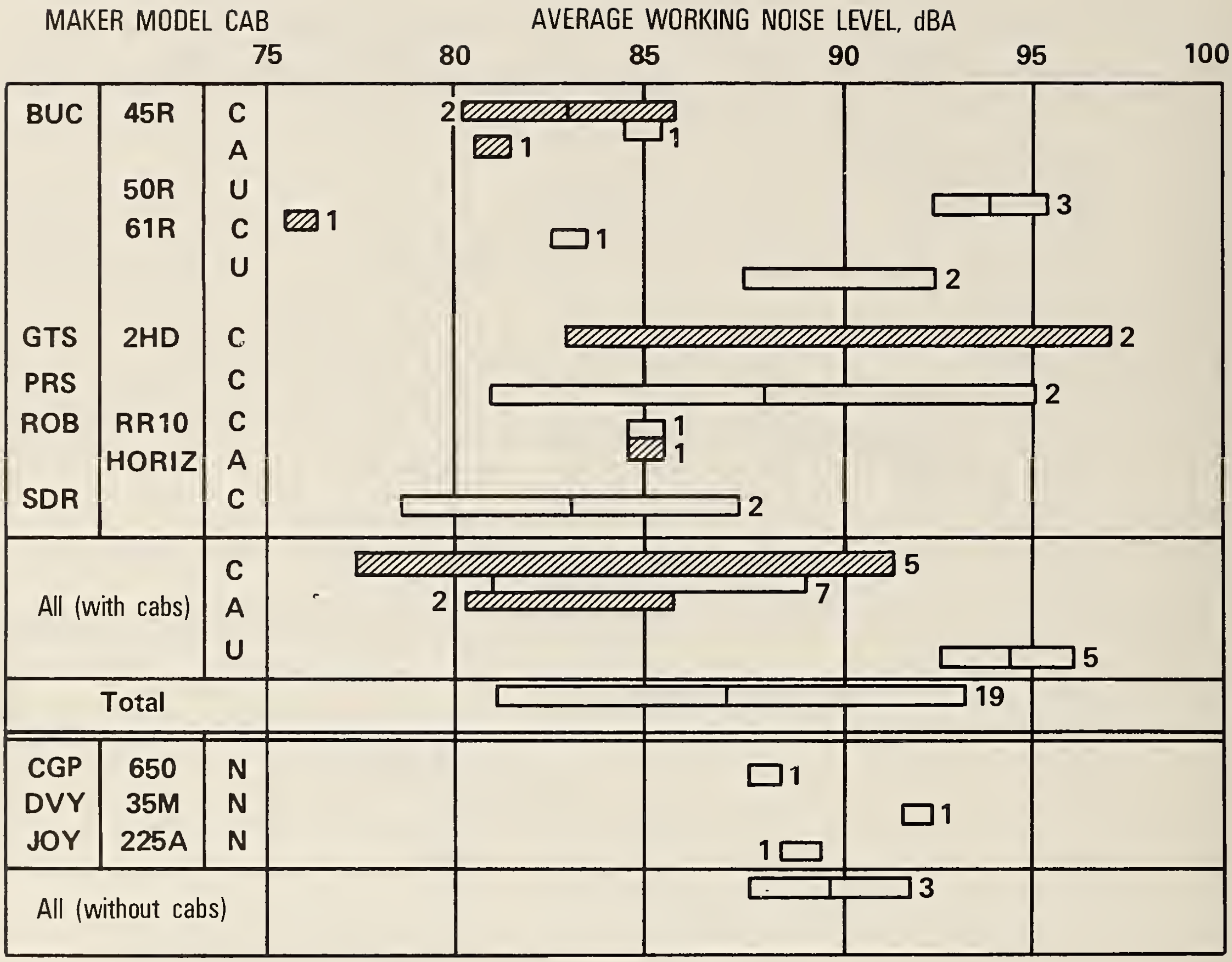


S = Single-engine scrapers

T = Tandem scrapers

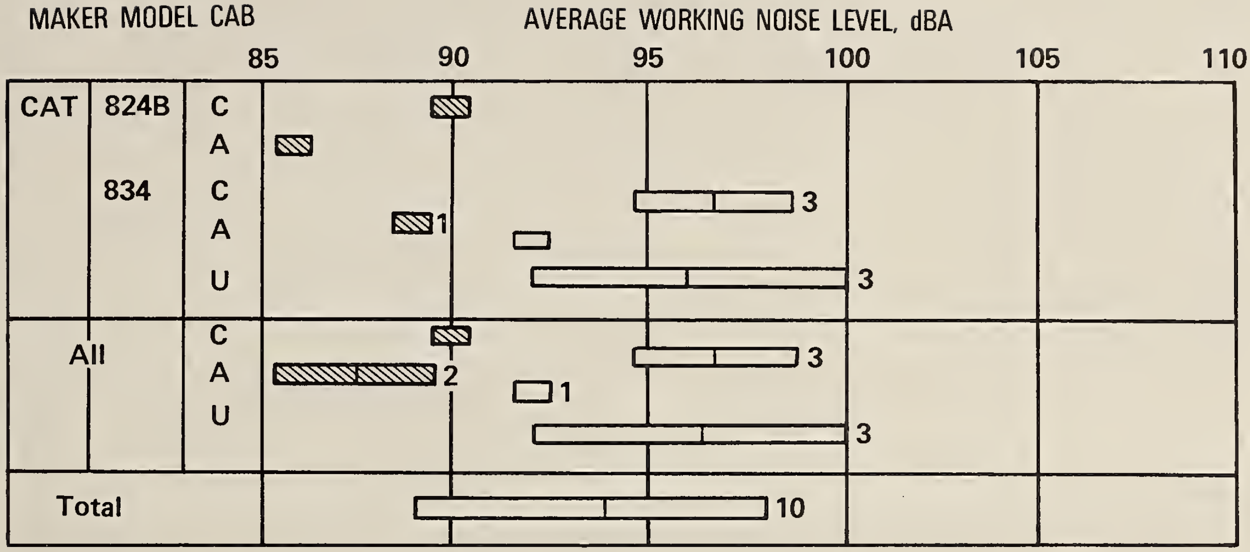
See figure B-1 for definitions of symbols

FIGURE B-5. - Working noise level of scrapers.



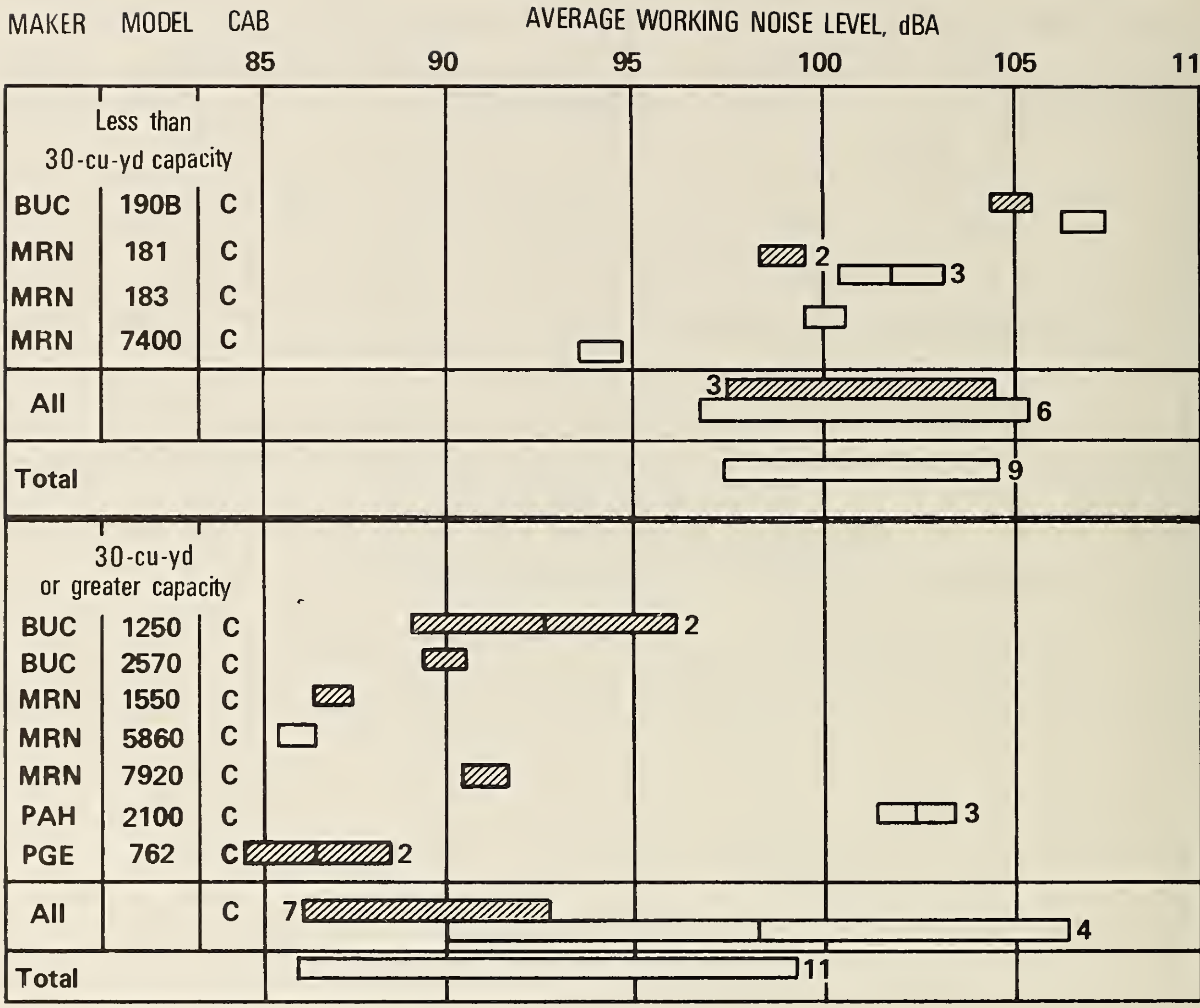
See figure B-1 for definitions of symbols

FIGURE B-6. - Working noise level of drills.



See figure B-1 for definitions of symbols

FIGURE B-7. - Working noise level of wheel dozers.



See figure B-1 for definitions of symbols

FIGURE B-8. - Working noise level of electric shovels and draglines.

3+5

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